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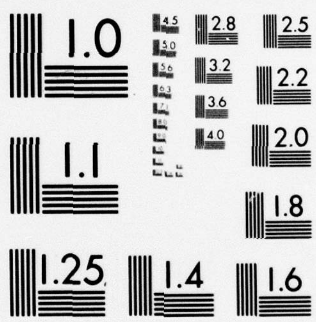


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# FOREIGN TECHNOLOGY DIVISION

PRECISION CASTING OF BLADES: WITH NO RESIDUAL WORK

by

Hsia Min Jen



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# PRECISION CASTING OF BLADES: WITH NO RESIDUAL WORK

Hsia Min Jen

Nowadays, the trend in producing the turbine blades of a jet engine is to replace forging by casting. The rapid progress in precision casting of recent years has made the transition from component casting with some residual machining to precision casting with no residual machine work. The new technique has the advantages of simpler production installation, reduced refining lab, shorter production period and raw material conservation. It also allows the production of parts having complex structure and difficult shape which are not easy to make with other methods.

A modern aviation jet engine has hundreds or even thousands of blades. They are fan blades, compressor blades, guidance blades and turbine blades. With the enormous number of blades on each engine, imagine the amount of machine work of an engine factory! Forging not only requires extensive equipment, but the forged body still needs machining. According to statistics, the machining of blades accounts for 60~70% of the total machine work of the engine factory and the utilization rate of material is only 10-20%. The production cost of the engine is driven up with 80% of the expensive material ending up as scraps. Therefore, people have always attempted to make blades by precision casting. The first casted blades are guidance blades (static blades) and later on turbine and compressor blaces (dynamic blades) are casted as well.

High temperature alloys are required in making the guidance and turbine blades because they are situated in high ambient temperature and work under harsh conditions. In the early stages, a small amount of

machining of the casted blades was still necessary due to insufficient accuracy. Unfortunately, the casted heat resistent alloy is very hard and difficult to machine. Grinding or electrochemical processes are time consuming and, as a result, the production cost was still relatively high. Great strides have been made in recent years in reducing the amount of residual machining to the extent of almost nonexistence.

## What is Precision Casting?

The term precision casting is used in contrast to the ordinary casting procedure. Ordinaly casting, as most people know, involves pouring the molten metal into a prefabricated mold and the desired parts are obtained upon solidification of the metal. The pattern used in casting is usually made of wood or metal. The pattern is placed in the flask which is then filled with sand to form the mold, hence the term sand casting. Molten metal is poured into the mold. This method of casting is different in precision from the investment casting which is used in making complex and high-precision parts. In addition to the ancient lost-pattern casting, the precision casting catagory also encompasses pressure or squeeze casting, metal pattern casting and shell casting. The current method of precision casting with no residual machine work often employs the lost-pattern casting (investment casting) which is the main topic of this article.

The technique of investment casting is used in the manufacturing of high precision parts and its principle was known in ancient China. In the Shang dynasty (1766-122 B.C.), the labor people of our country knew how to make very exquisite bronze vessels with a rather primitive method of lost-pattern casting. Although the modern investment casting has gone

through substantial evolution, its basic principle remains similar.

Depicted in Fig. 1 is the process of today's ceramic shell investment casting. First, wax is placed in a mold and pressed into a wax pattern which is a replica of the part to be made. Many wax patterns are soldered onto the pouring system to form an assembly. The assembly is then dipped in slurry, which is a mixture of refractory powder and binder, to form a thin layer of coating. Coarse grains of refractory are sprayed on it before the coating is dry. The assembly is then left to air dry and set, or it can be hardened by chemical means. The procedures of slurry coating,

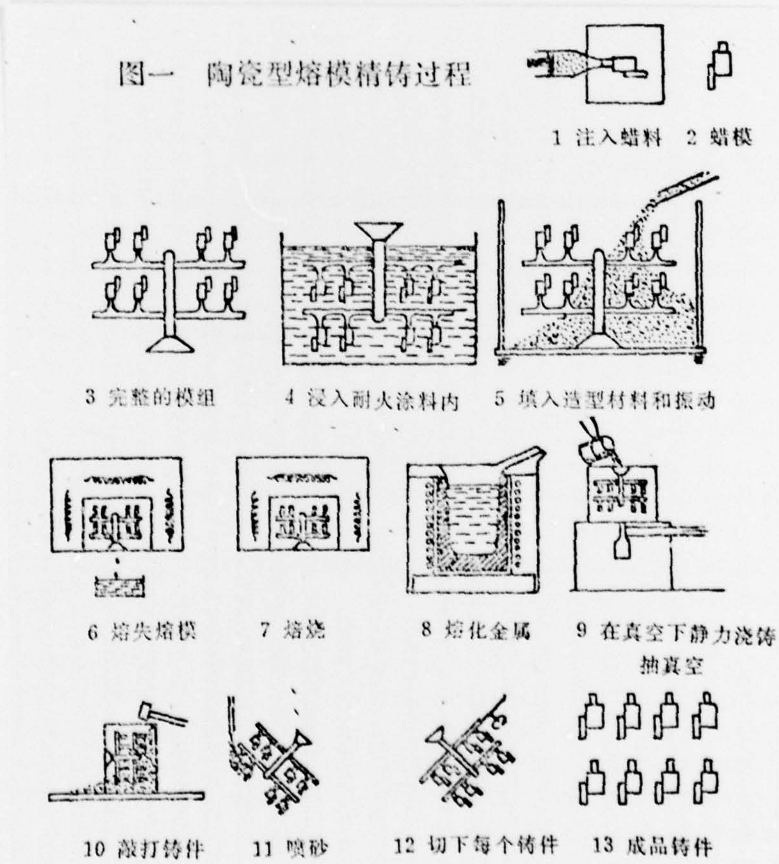


Fig. 1. The ceramic pattern precision casting process: 1. injecting wax; 2. wax pattern; 3. pattern assembly; 4. dipping in refractory slurry; 5. fill with mold material and vibrate; 6. melt out the wax pattern; 7. baking; 8. melting the metal; 9. gravity pouring in vacuum; 10. hammering; 11. sand blasting; 12. cutting; 13. end product parts.

Fig. 3 Pattern assembly after baking

refractory sprinkle and setting are repeated five to ten times until a shell of 4-12 mm thickness has formed on the surface of the pattern assembly. It is then heated so that the wax pattern melts and flows out. (Investment casting is also known as lost-wax casting.) The shell left behind is baked at high temperature and it is the mold in pouring the casting (See Fig. 3).

## Advantages of Investment Casting

Investment casting is generally used in producing parts of complex structures such as the turbine and guidance blades of a jet engine. The body of these blades is essentially an oar or variable cross sectional area and complex surface pattern. The hollow blades of a modern jet engine turbine have the additional complexity of the cooling channel at the center. Investment casting is practically the only way in producing such hollow blades. The second advantage of investment casting is its suitability for casting alloys of high strength, ductility, and hardness. Turbine and guidance blades are made of precisely these alloys. Of particular interest is the technique of vacuum melting and casting. Casting under vacuum gives blades of good metallurgical quality and consistent characteristics. Thirdly, the surface smoothness and dimension accuracy of investment casting products can be improved substantially with

proper precautions in the engineering and the operation. Parts requiring no residual machining are sometimes achievable. Finally, investment casting is most economical in the mass production of blades. It requires the least amount of equipment and raw material and has the shortest production period. As shown in Fig. 2, the investment casting process reduces the cost of principal material and the overall production cost of the blades by about 40% as compared to forged blades of similar metallurgical composition. Because of the stated advantages, investment casting is widely employed in producing turbine and guidance blades.

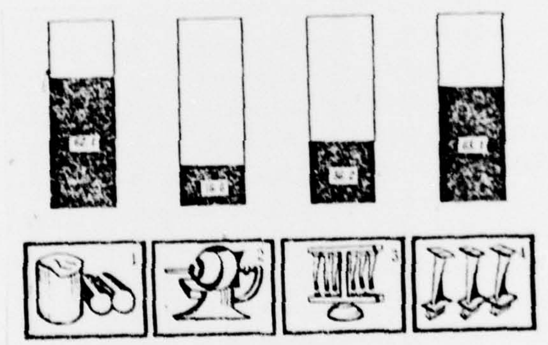

Fig. 2 Economical effects (%) of precision casting in the production of turbine blades (before finishing). The whole rectangles represent the costs when blades are produced by forging, shaded areas represent costs in the precision casting method.

1--principal material; 2--equipment depreciation; 3--installation cost; 4--manufacturing cost of product.

## Blades of No Residual Work

One of the development directions in precision casting today is to achieve no-residual-work blades, that is, the body portion of the casted blades requires no more machining than minor polishing or buffing. The research and development of ready-to-use blade casting is significant

due to the following reasons. Without post-cast machining, the useful life of a blade is extended since the fine grain crystalline layer of the surface will not be damaged. Secondly, since the manhours spent on machining of the blade body account for 60 to 85% of the total machine work, blades requiring no additional machining represent an enormous saving of the manhours on machining and an increase in production rate. Furthermore, high temperature alloys generally have very high strength and hardness and hence are difficult to machine. No residual work therefore means great savings on large amounts of expensive tooling and a reduced cost of production.

A turbine blade consists of the body, the arrow head and, sometimes, the crown. (See Fig. 4) The term "no residual work" in precision casting refers to the body only. The arrow head of the blade engages with the wheel disk and requires a tolerance of $\pm$ 0.01 - 0.02 mm which is still beyond today's technology of precision casting.

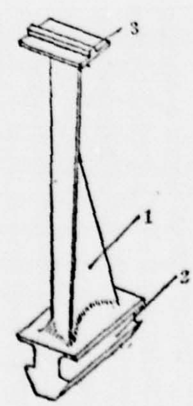


Fig. 4 Turbine blade: 1. body; 2, arrow head; 3. crown.

## How to Achieve No-Residual-Work Precision Casting

Stringent requirements are placed on the dimension accuracy, the surface smoothness and the metallurgical quality in achieving the no residual work condition. The smoothness of the surface should not be lower than $\nabla$ 7, and the metallurgical quality of the cast, especially the surface, must be outstanding. Basically, the casting technique for no residual work blades is no different from that of ordinary investment casting. The high quality products are made possible through rigorous control and improvement of the equipment, the raw material and the entire operational procedure. Listed below are the major points of consideration in precision casting of blades.

1. Precision mold. The mold used in precision casting of blades should meet the following requirements: surface dimension accurate to within $\pm$ 0.02 mm and surface smoothness no less than $\nabla$ 9. In the design of the precision mold, thermal contraction and shape deformation should be taken into account and compensated for in every stage of the accurately controlled operation.

2. Precision wax pattern: Dimension accuracy and stability and surface smoothness are also the requirements of the wax pattern. The mold material should possess properties like high resistance to heat and small coefficient of contraction. Some solid powder filler such as graphite or polyphenylethylene can be added to the mold material for the purpose of reducing the contraction. If the thickness of the machine part is large, a piece of cold wax can be placed in the pattern with a 1-2 mm gap between the two, and molten wax is then pressed into the gap. The contraction of wax upon solidification can be avoided by using powders

of wax in the pattern and squeezing the powder to form the mold. The pattern production is best carried out on a hydraulically transmitted automatic injection machine. Such a machine offers close control of the temperatures of the injected wax and the mold, and has adequate injection pressure and speed. The temperature of the pattern making room should be kept between 20 and 25$^{o}$ C.

3. Precision ceramic shell pattern: A ceramic shell pattern of high precision is essential in obtaining quality casting products. It should have smooth surfaces, stable thermal expansion characteristics, tolerable warping at high temperatures and adequate strength and porosity. Zircon and colloidal silica gel are commonly used surface layer coating material. Refractory such as kaolinite and silicate are used as the reinforcement layer coating. Opaque quartz glass, with a thermal expansion coefficient only 1/20 of that of ordinary quartz, has also been used as shell pattern material. In casting turbine blades, a certain amount of cobalt oxide is usually added to the surface coating for the control of the crystalline grain size of nickel based alloy cast. After the wax pattern is coated and dressed, it is heated in pressurized (4-6 atm.) steam to melt out the wax. The shell pattern, after "lost wax," is then baked under a temperature of about 1000$^{o}$ C to acquire some degree of strength and thermal stability.

4. Blade casting: High quality alloys are used in casting blades which require no residual work. Demanding requirements are placed on the composition, characteristics, and metallurgical quality (e.g. oxide impurity and gas content) of these alloys. The nickel based alloys generally used in this type of casting are formed under vacuum melting. Precision blades are cast in a vacuum furnace and the temperature, pressure and the

quality of the crucible are all under close control to avoid oxide impurities in the precision cast parts. Ideally a continuous operation vacuum melting and casting furnace should be used.

5. Treatment of cast parts: This is an important step in assuring the surface quality of the product. After the part is cast, damage should be avoided in cleaning and cutting. Blades of no residual machine work are sand blasted with aluminum oxide finer than #100, liquid sand blast is preferable. The surface shininess can be further improved by buffing. If heat treatment is needed, it should be carried out under an oxygen free environment.

6. Precision machining: Precision casting of no residual work blades reverses the usual procedure of machining the arrow head and the auxilliary base first and the blade body next. To ensure the accurate alignment of the blade body and the arrow head, the body should be machined first and the arrow head is then aligned and machined. The precision casting of blades minimized the amount of machining required on the blade body. A box type clamp is usually used in the machining of the arrow head with the body as the alighment reference. (See Fig. 5) The blade is first positioned on a surface-pattern-board, using the two end faces

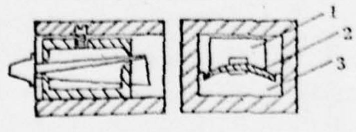


Fig. 5 Box type clamp
1. Orientation board (fixed); 2. blade; 3. set board.

as reference. Low melting point alloy (Wood's alloy) is poured into the box clamp and the arrow head is then machined. The low melting point alloy is melted out by steam after the machining is finished.

In addition to the considerations discussed above, accurate measuring instruments and methods are also essential in the engineering technique of precision casting of blades. Precision measurements are indispensable in the mold making, wax pattern inspection and the final stage of product evaluation.

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Figures by Wen Chen Chen

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